MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2016/2017

EME4076 – MECHANICAL VIBRATIONS

(All sections)

19 OCTOBER 2016
09:00 a.m. – 11:00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 9 pages including cover page with 5 Questions and 3 appendices.

2. Attempt **FOUR** out of **FIVE** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

Question 1

Figure Q1 shows a vibrometer which is fixed to a horizontal surface of a motor. The motor has an unbalance. This causes the motor to vibrate sinusoidally. Knowing that the natural frequency of the undamped spring-body system of the vibrometer shown in the figure is 5 Hz.

(a) Derive the equation of motion of the system.

[5 marks]

(b) If the motor is running at 750 rev/min, the amplitude of vibration of the suspended body of the vibrometer is observed to be 1 mm. What is the amplitude of vertical vibration of the motor?

[5 marks]

(c) Determine at what motor speed will the amplitude of motor vibration be the same as the amplitude of vibration of the vibrometer body given in part (b)?

[5 marks]

(d) If a small object is placed on the motor surface, it is observed that the object is started to dance and actually to lose contact to the surface when the amplitude of vibration recorded by the vibrometer is 2 mm. Determine the speed of the motor that will cause the small object to dance.
(Hint: the small object will lose contact to the motor surface when the reaction to the object is zero)

[10 marks]

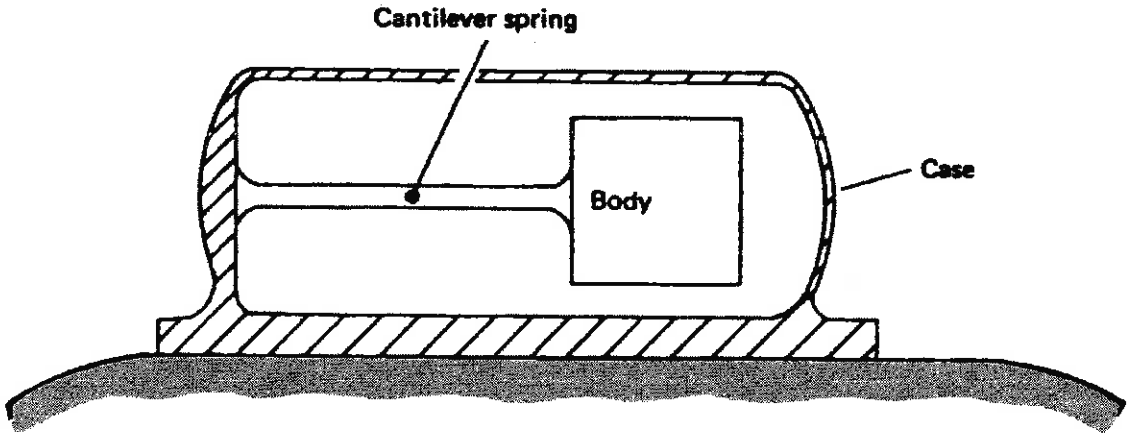

Figure Q1

Continued .....

Question 2

(a) A machine of mass 520 kg produces a vertical disturbing force which oscillates sinusoidally at a frequency of 25 Hz. The force transmitted to the floor is to have an amplitude, at this frequency, not more than 0.4 times that of the disturbing force in the machine. For this purpose, rubber mountings are to be used, which are available as units, each of which has a stiffness of 359 kN/m and a damping coefficient of 2410 N s/m. How many of these rubber mounting units are needed if arranging them in parallel?

[12 marks]

(b) The vibration of the floor of a laboratory is found to be simple harmonic motion at a frequency in the range 15–60 Hz (depending on the speed of some nearby reciprocating plant). It is desired to install in the laboratory a sensitive instrument which requires insulating from the floor vibration. The instrument is to be mounted on a small platform which is supported by three similar springs resting on the floor, arranged to carry equal loads; the motion is restrained to occur in a vertical direction only. The combined mass of the instrument and the platform is 40 kg: the mass of the springs can be neglected, and the equivalent viscous damping ratio of the suspension is 0.2. Calculate the maximum value for the spring stiffness if the amplitude of the transmitted vibration is not more than 10% of that of the floor vibration, over the given frequency range.

[13 marks]

Continued .....

Question 3

When transported, a space vehicle is supported in a horizontal position by two springs, as shown in Figure Q3. The vehicle can be considered to be a rigid body of mass m and radius of gyration h about an axis normal to the plane of the figure through the mass center G. The rear support has a stiffness k_1, and is at a distance a from G while the front support has a stiffness k_2, and is at a distance b from G. The only motions possible for the vehicle are vertical translation, x, and rotation, θ, in the vertical plane.

(a) Derive the equations of motion of the vehicle in terms of the given parameters.

[8 marks]

(b) Determine condition that will make the system uncoupled.

[8 marks]

(c) With condition given in part (b), determine the natural frequencies of the free vibrations of the vehicle and sketch the corresponding modes of vibration.

[9 marks]

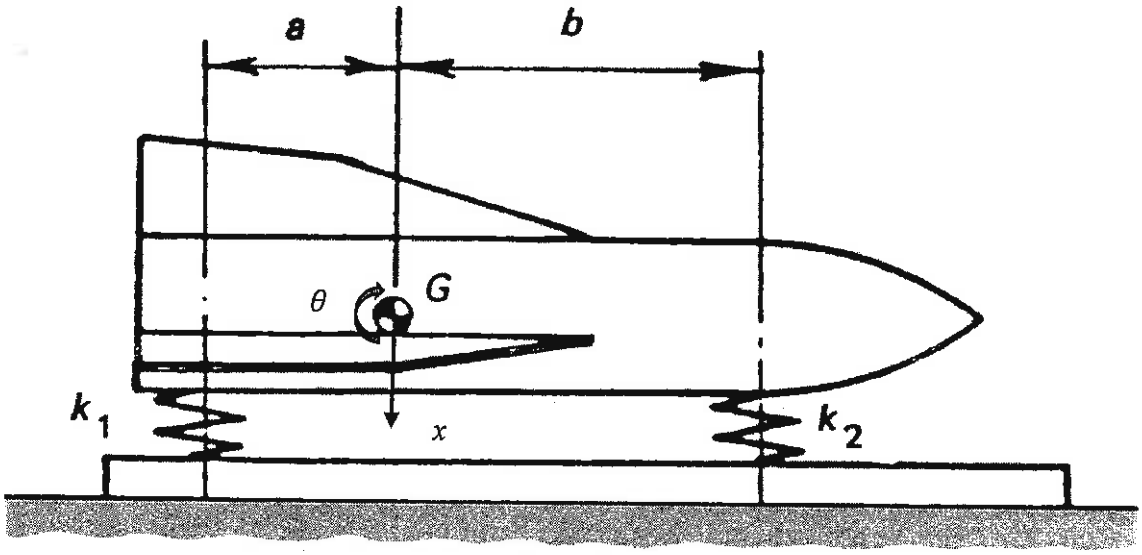

Figure Q3

Continued .....

Question 4

Figure Q4 shows a wooden floor, 6 m by 3 m, is simply supported along the two shorter edges and sagged at its own weight. The mass is 380 kg and the static deflection at the center under the self-weight is 7 mm. It is proposed to determine the dynamic properties of the floor by dropping a sand bag of mass $m_s = 50$ kg on it at the center, and to measure the response at that position with an accelerometer and a recorder. In order to select the instruments required, assuming a damping ratio of 0.05 determine

(a) the frequency of vibration which would be recorded;

[5 marks]

(b) the number of oscillations for the signal amplitude on the recorder to be reduced to half; and

[5 marks]

(c) the height of drop of the sand bag h so that the amplitude of vibration shall not exceed 10 mm, and the corresponding maximum acceleration.

[15 marks]

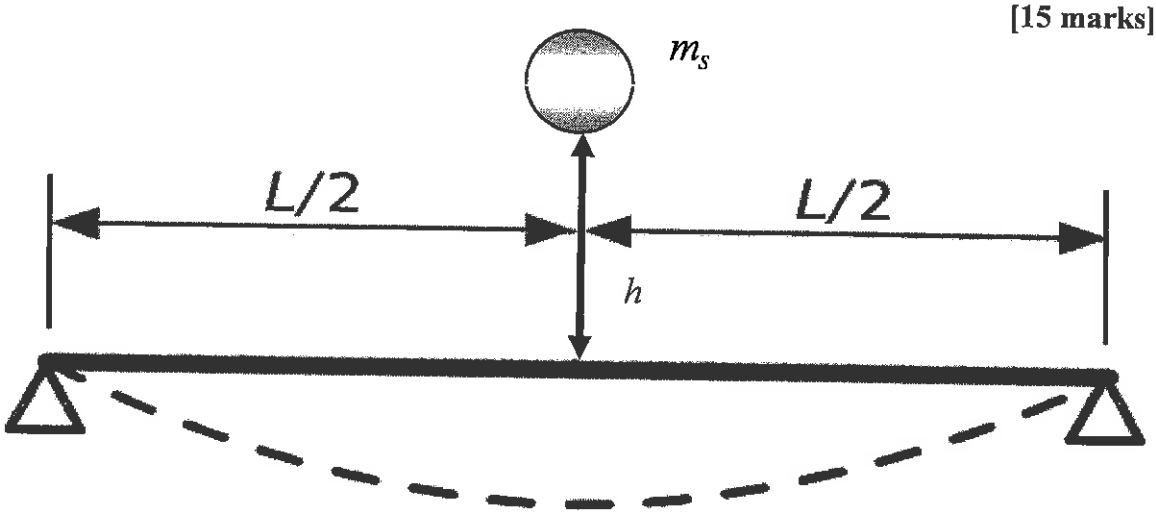

Figure Q4

Continued .....

Question 5

Figure Q5 shows an aircraft ejection seat which is used to eject the pilot from the aircraft in case of emergency. The seat can be modeled as a horizontal platform with negligible mass and the pilot can be treated as a rigid mass of 90 kg supported on the platform by the cushion of the seat. The cushion can be modeled as a spring with a stiffness of 10.9 kN/m. In the event of untoward incident, the seat will subject a constant vertically upward acceleration of 49 m/s^2 for 0.19 s in order to eject the pilot from the aircraft. Once the pilot is ejected, he/she will continue to move through the air. Knowing that the pilot is ejected vertically and neglecting the effect of air resistance.

(a) Derive the equation of motion of the system.

[5 marks]

(b) Determine the maximum height to which the pilot rises above the position of static equilibrium, and

[15 marks]

(c) the maximum acceleration to which the pilot is subjected.

[5 marks]

Figure Q5

Continued .....

Appendix 1

Vibrations

Equations of Motion

$$m\ddot{x} + c\dot{x} + kx = F_0 \sin \omega t$$

General Solution

$$x(t) = x_c(t) + x_p(t)$$

$$x_p(t) = D \sin(\omega t - \varphi)$$

$$D = \frac{F_0/k}{\sqrt{[1-r^2]^2 + (2\zeta r)^2}} \qquad \text{where} \quad r = \frac{\omega}{\omega_n}$$

$$\varphi = \tan^{-1} \frac{2\zeta r}{1-r^2}$$

$$x_c(t) = D_1 e^{\lambda_1 t} + D_2 e^{\lambda_2 t} \qquad \zeta > 1$$

$$x_c(t) = (B + Ct) e^{-\omega_n t} \qquad \zeta = 1$$

$$x_c(t) = e^{-\zeta \omega_n t} (B \cos \omega_d t + C \sin \omega_d t) \qquad \zeta < 1$$

$$\omega_n = \sqrt{k/m} = 2\pi f_n, \qquad f_n = \frac{1}{\tau_n} = \frac{\omega_n}{2\pi}$$

$$\zeta = \frac{c}{2m\omega_n}$$

$$\lambda_{1,2} = -\zeta \omega_n \pm \omega_n \sqrt{\zeta^2 - 1} \qquad \zeta \geq 1$$

$$\omega_d = \omega_n \sqrt{1-\zeta^2} \qquad \zeta < 1$$

Force and Displacement Transmissibility

$$\frac{F_T}{F_0} = \frac{X}{Y} = \left[\frac{1+(2\zeta r)^2}{(1-r^2)^2 + (2\zeta r)^2}\right]^{\frac{1}{2}}$$

Rotating Unbalance: Amplitude of Response

$$X = \frac{m_0 e}{m + m_0} \frac{r^2}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}}$$

Fourier's series

$$x(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos n\omega t + b_n \sin n\omega t]$$

$$a_n = \frac{2}{\tau}\int_0^{\tau} x(t) \cos n\omega t \, dt \qquad b_n = \frac{2}{\tau}\int_0^{\tau} x(t) \sin n\omega t \, dt$$

Unit response function (underdamped)

$$h(t-\tau) = \frac{e^{-\xi\omega_n(t-\tau)}}{m\omega_d} \sin \omega_d (t-\tau)$$

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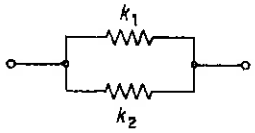
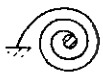
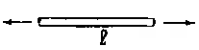
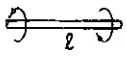
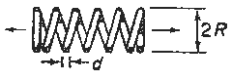
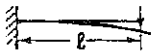
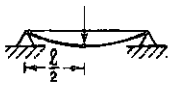
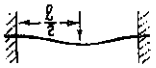
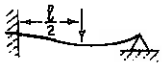
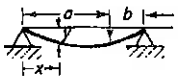
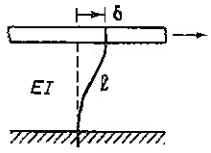
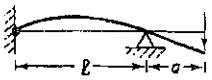
Appendix 2

Table of Spring Stiffness

	$k = \dfrac{1}{1/k_1 + 1/k_2}$	
	$k = k_1 + k_2$	
	$k = \dfrac{EI}{l}$	I = moment of inertia of cross-sectional area l = total length
	$k = \dfrac{EA}{l}$	A = cross-sectional area
	$k = \dfrac{GJ}{l}$	J = torsion constant of cross section
	$k = \dfrac{Gd^4}{64nR^3}$	n = number of turns
	$k = \dfrac{3EI}{l^3}$	k at position of load
	$k = \dfrac{48EI}{l^3}$	
	$k = \dfrac{192EI}{l^3}$	
	$k = \dfrac{768EI}{7l^3}$	
	$k = \dfrac{3EIl}{a^2b^2}$	$y_x = \dfrac{Pbx}{6EIl}(l^2 - x^2 - b^2)$
	$k = \dfrac{12EI}{l^3}$	
	$k = \dfrac{3EI}{(l+a)a^2}$	
	$k = \dfrac{24EI}{a^2(3l+8a)}$	

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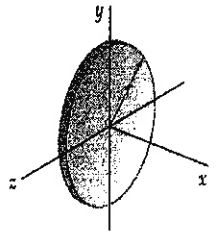
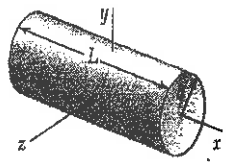
Appendix 3: Mass Moment of Inertia of Homogenous Solids



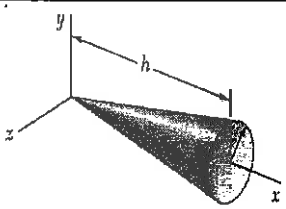
$I_x = \frac{1}{2}mr^2$

$I_y = I_z = \frac{1}{4}mr^2$



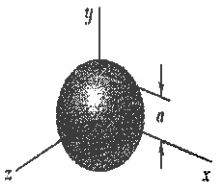
$I_x = \frac{1}{2}ma^2$

$I_y = I_z = \frac{1}{12}m(3a^2 + L^2)$

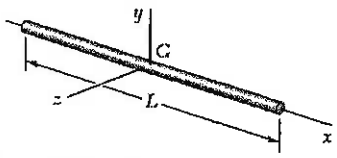


$I_x = \frac{3}{10}ma^2$

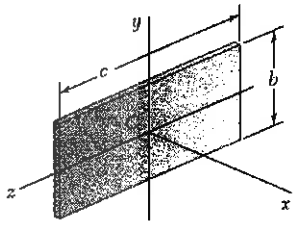
$I_y = I_z = \frac{3}{5}m(\frac{1}{4}a^2 + h^2)$



$I_x = I_y = I_z = \frac{2}{5}ma^2$



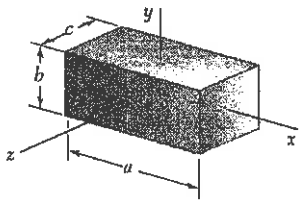
$I_y = I_z = \frac{1}{12}mL^2$



$I_x = \frac{1}{12}m(b^2 + c^2)$

$I_y = \frac{1}{12}mc^2$

$I_z = \frac{1}{12}mb^2$



$I_x = \frac{1}{12}m(b^2 + c^2)$

$I_y = \frac{1}{12}m(c^2 + a^2)$

$I_z = \frac{1}{12}m(a^2 + b^2)$

End of Paper